

# **A Space Dust Experiment (SPADUS) for Measurement of the Distribution of Man-made and Natural Dust in Near-Earth Space for Flight on the P91-1 Advanced Research and Global Observation Satellite (ARGOS)**

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## **LONG-TERM GOALS**

The primary goal of SPADUS is to develop instrumentation for the first-ever measurement of individual dust particle velocities, trajectories, and spatial distributions with sufficient accuracy to identify (by the orbital characteristics of the dust in near-Earth space) their parent bodies.

Another goal includes the accurate measurement of particle mass distributions and dust fluxes, with immunity to possible intense backgrounds from radiation belts and/or intense magnetic fields.

Finally, it is the goal of SPADUS to develop, design, and implement strategies for large-area sensors and sensor arrays to maximize data collection under conditions of low particle flux for future investigations of debris dust, interplanetary dust, and natural debris streams.

## **OBJECTIVES**

In furtherance of these objectives—with support from ONR Grant No. N00014-91-J-1716, NASA Grant NAGW-3078, and in-house funding from the Naval Research Laboratory and Lockheed Space Sciences Laboratory—we have developed the SPADUS experiment. This instrument was launched into a Sun-synchronous orbit on the ARGOS P91-1 mission on February 23, 1999. The prime scientific and engineering objectives of SPADUS are to:

1. Provide definitive measurements of the mass, flux, velocity and arrival directions of individual particles in near-Earth space, both for man-made particles (orbital debris) and for particles of natural origin. These measurements will be carried out over a particle size range in which there are little quantitative data (particle diameter range ~2 to 200 microns);
2. Evaluate the trajectories of incident dust particles, and thus determine their likely origin as either man-made orbital debris (occupying primarily bound, near-circular orbits) or from natural sources—e.g. comets, asteroids, zodiacal cloud (occupying mainly unbound hyperbolic orbits about Earth);
3. Search for transient dust flux increases from interplanetary dust stream encounters;

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4. Obtain direct data on orbital and size distributions for small debris particles; and
5. Characterize the spatial and temporal characteristics of orbital debris (i.e., debris streams).

The SPADUS flight instrument, shown in figure 1, consists of: (a) a dust trajectory system consisting of two identical dust sensor arrays (D1 and D2 planes); (b) a digital electronics box containing the Ancillary Diagnostic Sensor (ADS) charged-particle detection system; and (c) the analog electronics box.

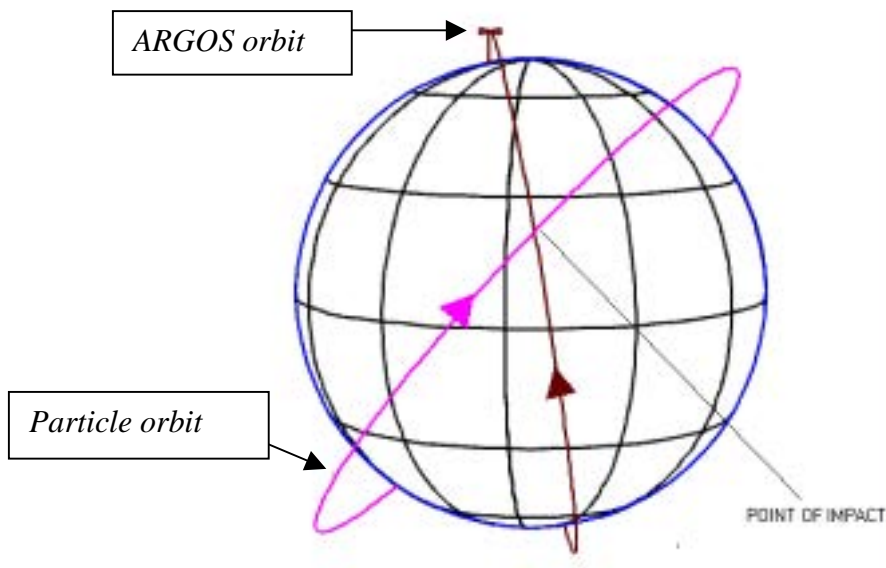


**Figure 1: Photograph of the SPADUS Flight Instrument showing the dust trajectory system, the digital electronics box, and the analog electronics box.**

Following the launch of *ARGOS* P91-1, the SPADUS instrument is the first to provide accurate information concerning particle trajectories and temporal variations in the microparticle environment in low-Earth orbit, a region of great practical importance for satellites and human activity in space. An example of the orbit of one of the particles which impacted SPADUS is shown in Figure 2.

## **APPROACH**

The experimental approach used in the SPADUS instrument to achieve these objectives uses the polyvinylidene fluoride (PVDF) dust sensor developed at the University of Chicago under earlier NASA and ONR support. PVDF detectors have been incorporated in the DUCMA dust instrument on the *VEGA* missions to Comet Halley, in the (classified) *ERIS* mission, and are currently included in the Cosmic Dust Analyzer on the *Cassini* mission to Saturn and on the Dust Flux Monitor Instrument (DFMI) being carried aboard the *Stardust* mission to Comet WILD-2.



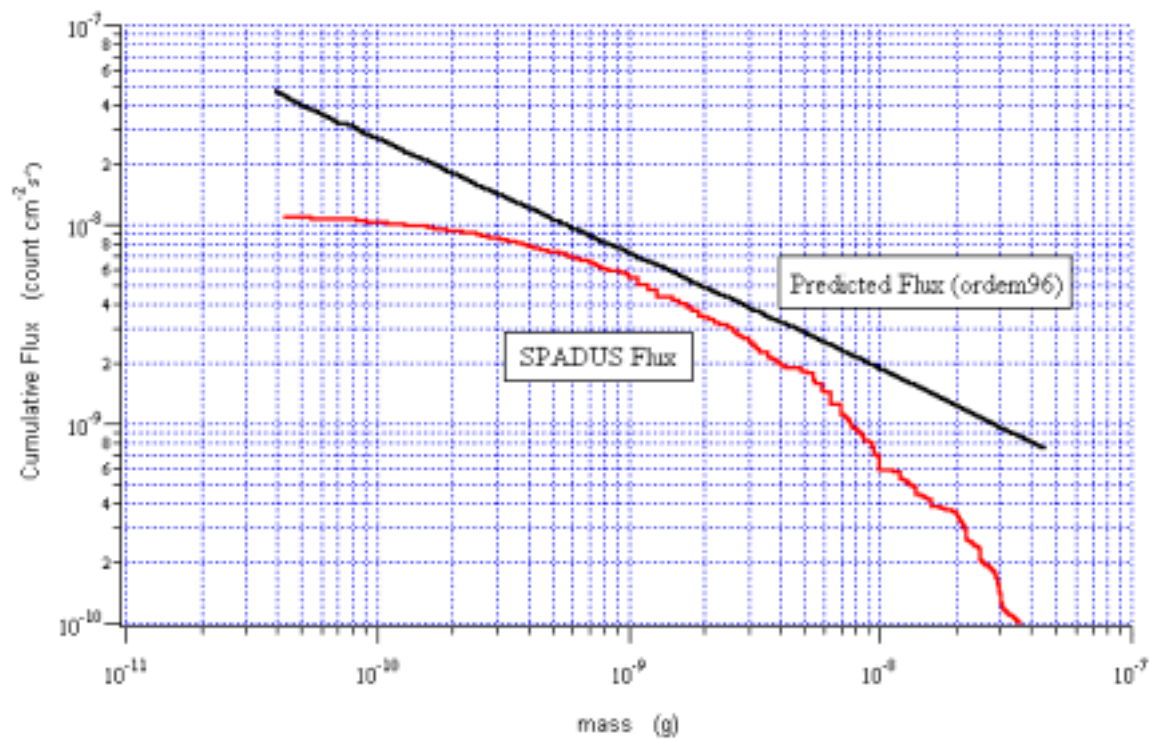
**Figure 2: The trajectory of an orbital debris particle which impacted SPADUS on day 100 of 1999 (April 10, 1999).**

## WORK COMPLETED

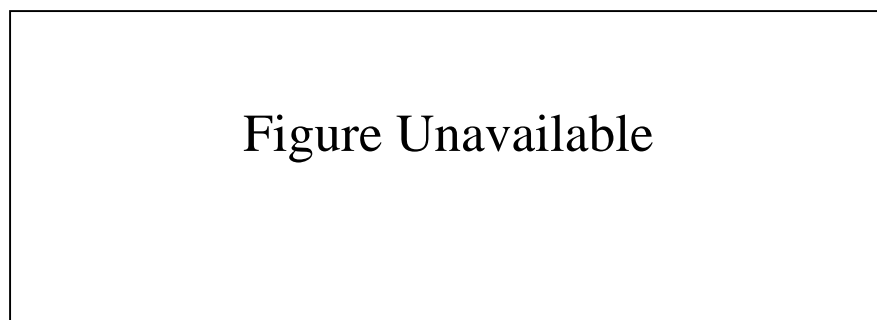
During FY2001 the following tasks were accomplished:

1. Analysis of the flight data from the SPADUS Dust Trajectory System has continued. As of September 2, 2001, a total of 366 dust particle impacts on the SPADUS D1 array were recorded. Of these, 35 were determined to result from D1-D2 impacts, so that the orbital elements of the particles could be determined, as discussed in references 1 and 2. From the orbital elements, 28 of the 35 impacts were found to result from orbital debris impacts, and the remaining 7 resulted from interplanetary particle impacts.
2. The cumulative particle flux vs. particle mass measured for the SPADUS instrument from ARGOS launch has continued up to September 2, 2001, and is shown in Figure 3. Also shown is the flux predicted by the ORDEM96 debris model.
3. In Figures 4 and 5, the plots of the number of impacts measured have been expanded to include the data obtained during FY2001. Figure 4 shows the cumulative count each day after launch while Figure 5 shows the number of impacts during each four-day interval after launch. The large enhancement around day 400 and interval 100 (March 25—April 1) corresponds to the detection of the debris from the explosion of the upper stage of a Chinese Long March 4 rocket, as discussed in Reference 3.

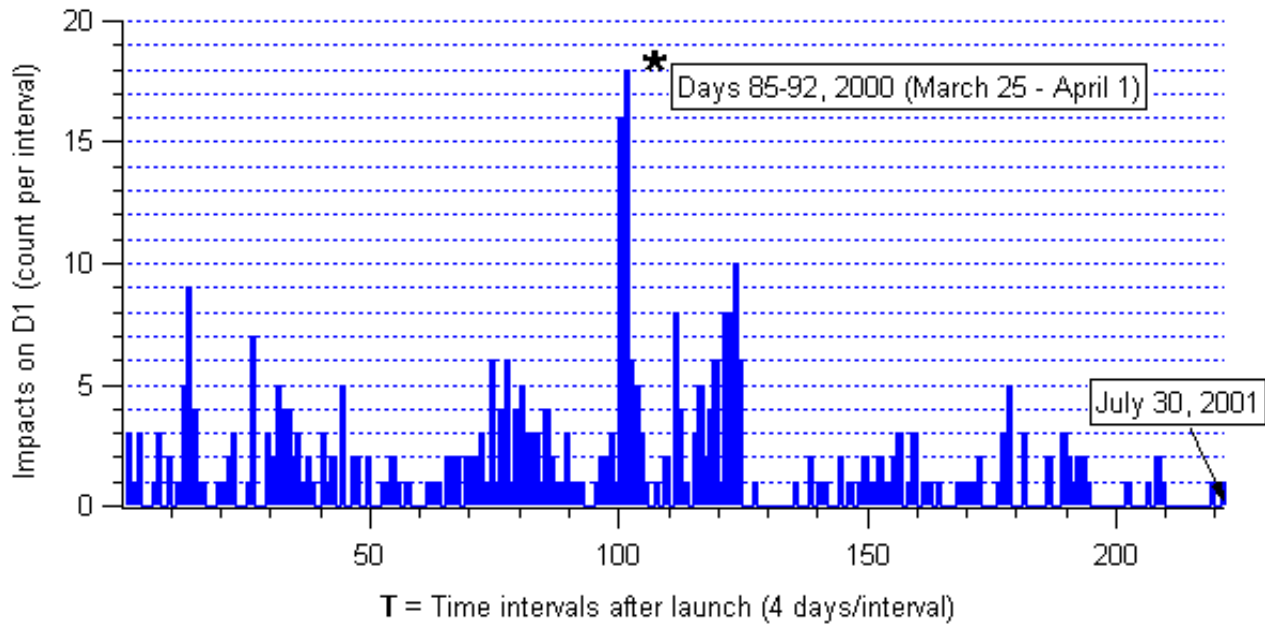
Throughout FY2001, no short-term enhancements similar to those around March 25—April 1, 2000 were measured by SPADUS.



**Figure 3:** *The cumulative particle flux vs. particle mass measured for the SPADUS instrument from ARGOS launch up to September 2, 2001.*



**Figure 4:** *Plot of the accumulated SPADUS D1 counts from ARGOS launch to September 2, 2001. The strong increase indicated by the asterisk corresponds to the asterisk in Figure 5.*



**Figure 5: Number of impacts per four-day interval from SPADUS launch until the last event on July 30, 2001 vs. Interval number.**

## IMPACT/APPLICATIONS

The SPADUS flight data from February 1999 to September 2001 has demonstrated that PVDF-based dust instruments in space—which utilize two planar arrays of PVDF dust sensors in a TOF arrangement—can provide useful measurements of particle velocity, mass distribution, flux, trajectory, and particle orbital elements. The SPADUS dust data has established a first semi-quantitative picture of the nature of the orbital debris and interplanetary particle orbits which are encountered at an Earth altitude of ~850 km.

The SPADUS instrument is a first-generation dust instrument. Future PVDF instruments based on the SPADUS design but utilizing, for example, two-dimensional PVDF dust sensors or a large number of small-area sensors—and having a much greater area than SPADUS (several m<sup>2</sup>)—would provide excellent trajectory data (< 1° error in angle determination and ~1% error in velocity measurements) and would have sufficient area for quantitative measurements of orbital, interplanetary, and interstellar dust.

## RELATIONSHIP TO OTHER PROGRAMS AND PROJECTS

The ONR SPADUS work is strongly related to other dust and debris projects within NASA. Specifically:

1. The University of Chicago High Rate Detector (HRD) instrument for the NASA/ESA *Cassini* mission to Saturn was developed by the same scientific and technical staff responsible for SPADUS development (funded through JPL).

2. The SPADUS concept served as the basis for the University of Chicago Dust Flux Monitor Instrument (DFMI) which was launched on NASA's *Stardust* mission.
3. The study of the small particle debris environment in near-Earth orbit has been identified as a high priority by NASA, ESA, and other governmental agencies concerned with space activities, as indicated by the following documents:
  - a. European Space Agency, "Space Debris," SP-1109, Paris, 1988.
  - b. R.C. Reynolds and A.E. Potter, Jr., "Orbital Debris Research at NASA Johnson Space Center." Technical Memorandum 102155, National Aeronautics and Space Administration, Houston, Texas, 1989.
  - c. U.S. National Security Council, "Report on Orbital Debris," Washington, D.C., 1989
  - d. U.S. Congress, General Accounting Office, "Space Program: Space Debris a Potential Threat to Space Station and Shuttle," Washington, D.C., 1990.
  - e. U.S. Congress, Office of Technology Assessment, "Orbiting Debris: A Space Environmental Problem—Background Paper," OTA-BP-ISC-72, Washington, D.C. U.S. Government Printing Office, 1990.
  - f. "Preservation of Near-Earth Space for Future Generations." J.A. Simpson, ed. Cambridge University Press, 1994.

#### **PUBLICATIONS FROM ONR-SPONSORED WORK: FY2001**

"The Space Dust (SPADUS) Instrument Aboard the Earth-Orbiting ARGOS Spacecraft: I. Instrument Description," A.J. Tuzzolino, R.B. McKibben, J.A. Simpson, S. BenZvi, H.D. Voss, H. Gursky, *Planetary and Space Science*, 49 (2001) 689-703.

"The Space Dust (SPADUS) Instrument Aboard the Earth-Orbiting ARGOS Spacecraft: II. Results from the First 16 Months of Flight," A.J. Tuzzolino, R.B. McKibben, J.A. Simpson, S. BenZvi, H.D. Voss, H. Gursky, *Planetary and Space Science*, 49 (2001) 705-729.

"In-Situ Detections of a Satellite Breakup by the SPADUS Instrument," A.J. Tuzzolino, R.B. McKibben, S. BenZvi, H.D. Voss, H. Gursky, and N.L. Johnson, To appear in the Proceeding of the Third International Conference on Space Debris, Esoc, Darmstadt, Germany, March 19-21, 2001.